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Optical spectroscopy of the γ-ray bright blazars PKS 0447−439 and PMN J0630−24

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ABSTRACT

The large majority of sources detected by the *Fermi Gamma-ray Space Telescope* are blazars, belonging in particular to the blazar subclass of BL Lacertae objects (BL Lacs). BL Lacs often have featureless optical spectra, which make it difficult and sometimes impossible to determine their redshifts. This presents a severe impediment for the use of BL Lacs to measure the spectrum of the extragalactic background light through its interaction with high-energy γ-ray photons. I present here high-quality optical spectroscopy of two of the brightest γ-ray blazars, namely, PKS 0447−439 and PMN J0630−24. The medium-resolution and high signal-to-noise ratio optical spectra show clear absorption lines, which place these BL Lacs at relatively high redshifts of $z \geqslant 1.246$ for PKS 0447−439 and $z \geqslant 1.238$ for PMN J0630−24.

Key words: galaxies: active – BL Lacertae objects: individual: PKS 0447−439, PMN J0630−24

1 INTRODUCTION

Since its launch in 2008, the *Fermi Gamma-ray Space Telescope* has surveyed the sky with its Large Area Telescope (LAT; Atwood et al. 2009). The deep and uniform exposure, good per-photon angular resolution and stable response of the LAT has delivered the most sensitive and best-resolved all-sky survey to date in the 100 MeV to 100 GeV energy range. A significant result delivered by the *Fermi Gamma-ray Space Telescope* was to show that the extragalactic high-energy γ-ray sky is dominated by blazars. In particular the blazar subclass of BL Lacertae objects (BL Lacs) dominates the number counts in the recently released *Fermi* Second Source Catalog (Abdo et al. 2011).

A major science goal for the *Fermi* mission is to constrain the near-infrared (near-IR) to ultraviolet (UV) spectrum of the extragalactic background light (EBL) through its interaction with high-energy γ-rays from extragalactic sources (e.g., Abdo et al. 2010). The opacity of the Universe to high-energy γ-rays can in principle be measured from the observed γ-ray spectra of extragalactic sources if their intrinsic γ-ray spectra are known. Therefore, this method requires knowledge of the redshift of the extragalactic source. However, BL Lacs usually have optical spectra with only weak both emission and absorption features, which makes their redshift determination difficult and often impossible (e.g., Landt et al. 2002; Sbarufatti et al. 2005).

Here I present results from high-quality optical spectroscopy that allow a reliable redshift determination for two of the γ-ray brightest BL Lacs in the southern sky, namely, PKS 0447−439 and PMN J0630−24 (Abdo et al. 2009). Section 2 gives the details of the optical spectroscopic observations, whereas I discuss the redshift determination in Section 3. Section 4 presents the conclusions.

2 THE OPTICAL SPECTROSCOPY

The sources PKS 0447−439 and PMN J0630−24 are part of the Deep X-ray Blazar Survey (DXRBS; Perlman et al. 1998; Landt et al. 2001) within which they were classified as BL Lacs without a reliable redshift. For both sources Landt & Bignall (2008) presented deep, high angular resolution radio maps that provided accurate source positions. Based on these radio observations it is clear that the optical finder and optical spectrum of the source PKS 0447−439 presented by Craig & Fruscione (1997), whose redshift of $z = 0.107$ is currently listed in the NASA/IPAC Extragalactic Database (NED), must be misidentifications.

In order to improve on the redshift determination of all featureless DXRBS BL Lacs proposals for high-quality optical spectroscopy were successfully submitted to the Magellan 6.5 m, Cerro Tololo Inter-American Observatory (CTIO) 4 m and European Southern Observatory (ESO) New Technology Telescope (NTT) 3.6 m telescopes. The BL Lacs PKS 0447−439 and PMN J0630−24 were observed at both

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Table 1. Log of optical spectroscopy

Object Name	Observation date	Observatory	Grism properties Dispersion (Å pixel^{-1})	Range (Å)	Exposure (s)
(1)	(2)	(3)	(4)	(5)	(6)
PKS 0447−439	2007 Jan 21	NTT 3.6 m	1.64	3680 – 7036	900
	2007 Mar 20	CTIO 4 m	1.91	3360 – 9450	900
PMN J0630−24	2007 Jan 21	NTT 3.6 m	1.64	3680 – 7036	900
	2007 Mar 21	CTIO 4 m	1.91	3360 – 9450	1800

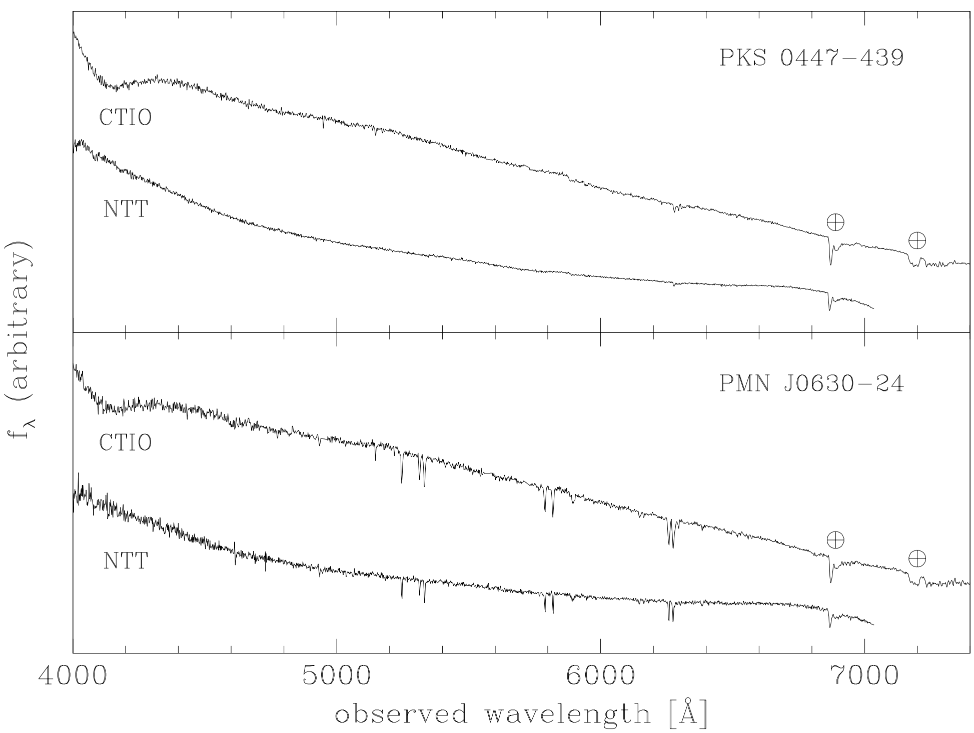

Figure 1. Optical spectra of the BL Lacs PKS 0447−439 (upper panel) and PMN J0630−24 (lower panel) shown in the observer's frame. In each panel the upper and lower spectrum are from the CTIO 4 m and NTT 3.6 m telescopes, respectively. Telluric absorption bands are indicated by circled plus signs.

the CTIO 4 m and NTT 3.6 m observatories and Table 1 gives the details of the observational set-up. Since any emission or absorption features in the spectra of these BL Lacs were expected to be weak, the observational strategy aimed at obtaining data of both a medium spectral resolution and a relatively high signal-to-noise ratio (S/N $\gtrsim$ 50).

The long-slit spectra were reduced using standard routines from the IRAF software package. In particular the 2-dimensional spectral files were trimmed, overscan- and bias-subtracted, normalized, rectified and wavelength-calibrated. Subsequently the spectrum was extracted and the 1-dimensional spectral file flux-calibrated using photometric standard stars observed the same night. The final spectra were corrected for Galactic extinction using the IRAF task *onedspec.deredden* with input A_V values derived from Galactic hydrogen column densities published by Dickey & Lockman (1990). The results are shown in Fig. 1.

The final average signal-to-noise ratio of all spectra is S/N $\sim$ 80. The CTIO spectra were obtained under good seeing conditions, whereas patchy cloud was present during the NTT night. The observed flux at $\lambda = 5500$ Å in the CTIO spectra is 4.39×10^{-15} erg s^{-1} cm^{-2} Å^{-1} for PKS 0447−439 and 1.18×10^{-15} erg s^{-1} cm^{-2} Å^{-1} for PMN J0630−24. I note that the bump and spectral upturn visible in the CTIO spectra at an observed wavelength of $\lambda \lesssim 4200$ Å and the slight spectral downturn visible in the NTT spectra at $\lambda \gtrsim 7000$ Å are due to the poor spectral response of the grisms in these regions.

3 REDSHIFT DETERMINATION

The optical spectra of the two BL Lacs PKS 0447−439 and PMN J0630−24 show clear absorption features but no emission lines. The absorption features are prominent and numerous in the spectra of the source PMN J0630−24, whereas

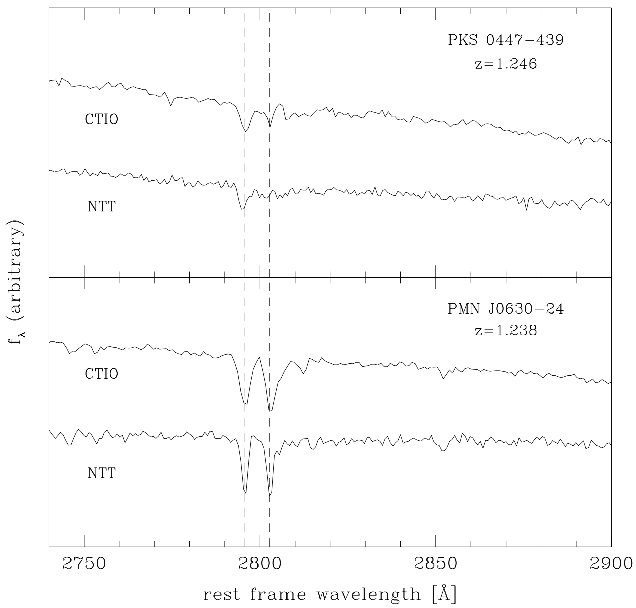

Figure 2. Optical spectra of the BL Lacs PKS 0447−439 (upper panel) and PMN J0630−24 (lower panel) shown in the rest frame. Based on the Mg II λ2800 doublet in absorption (marked by the vertical dashed lines) detected in both the CTIO 4 m and NTT 3.6 m spectra the redshift for PKS 0447−439 is $z \geqslant 1.246$ and that of PMN J0630−24 is $z \geqslant 1.238$.

only weak absorption features are detected in the spectra of the source PKS 0447−439. Based on the Mg II λ2800 doublet in absorption, which is clearly detected in all spectra (see Fig. 2), the redshift for the source PKS 0447−439 is $z \geqslant 1.246$ and that of the source PMN J0630−24 is $z \geqslant 1.238$. The observed Mg II equivalent widths are $W_\lambda = 0.3$ Å and 1.4 Å for PKS 0447−439 and PMN J0630−24, respectively. Other absorption lines detected in the spectra of PMN J0630−24 are Fe II lines, most notably Fe II λ2382, Fe II λ2586 and Fe II λ2600.

Due to the lack of spectroscopic redshifts in numerous BL Lacs several authors have investigated alternative methods to estimate this quantity. The method of Piranomonte et al. (2007) uses the fact that BL Lacs are hosted by luminous ellipticals of almost constant luminosity (e.g., Wurtz et al. 1996; Urry et al. 2000). Then, assuming a plausible lower limit for the jet/galaxy ratio of a featureless BL Lac one can derive a lower limit on the redshift from the observed optical V magnitude. Based on this method Landt & Bignall (2008) estimated a lower limit on the redshift of the source PKS 0447−439 of $z > 0.176$, assuming a jet/galaxy ratio of ten. Clearly, this lower limit strongly underestimates the true redshift of this BL Lac.

Similarly, Prandini et al. (2011) have presented an estimate of the redshift of the source PKS 0447−439 of $z = 0.2 \pm 0.05$. Their method assumes that the spectral slopes of the *Fermi* LAT γ-ray spectrum and that measured at very high γ-ray energies by ground-based Cherenkov telescopes are the same. Then, any observed differences between the two γ-ray spectra are attributed to the interaction with the EBL photons, which will be stronger at higher energies and will depend on the redshift of the source. However, the major unknown quantity in the application of this method is the spectrum of the EBL.

Recently, Rau et al. (2012) have introduced a method to estimate the redshift of a featureless BL Lac based on the fact that absorption by neutral hydrogen along the line of sight will cause a prominent absorption feature in the broad-band spectrum. Then, a power-law fit to the near-IR to UV (quasi-simultaneous) spectral energy distribution of a BL Lac can place an upper limit for low-redshift sources and give an estimate for high-redshift sources. These authors obtained for the source PMN J0630−24 a redshift of $z = 1.60^{+0.10}_{-0.05}$, which is above the value obtained from optical spectroscopy. However, since no emission lines are detected in the optical spectrum of the source PMN J0630−24, it cannot be excluded that the observed absorption lines are due to an intervening system rather than the host galaxy.

4 CONCLUSIONS

I have presented high-quality (medium-resolution, high signal-to-noise ratio) optical spectroscopy of two of the γ-ray brightest BL Lacs, namely, PKS 0447−439 and PMN J0630−24. Based on a clear detection of the Mg II λ2800 doublet in absorption the redshift for the source PKS 0447−439 is $z \geqslant 1.246$ and that of the source PMN J0630−24 is $z \geqslant 1.238$. Alternative methods proposed so far to estimate the redshifts of featureless BL Lacs give in the case of PKS 0447−439 a relatively low value of $z \sim 0.2$ and in the case of PMN J0630−24 an overestimate of $z \sim 1.6$. Therefore, high-quality optical spectroscopy that allows the detection of even the weakest features in the spectra of BL Lacs remains an absolute necessity.

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